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14. ABSTRACT
This TOP provides procedures for evaluating a simulator. It is geared towards a helicopter simulator but could also be used for a fixed-wing aircraft simulator. Simulators are designed with a limited mission. Full understanding of that mission is required so that an appropriate evaluation can be made. Failure to evaluate to the specific mission will result in shortcomings and deficiencies being identified that are outside of the intent of the simulator designer and as such, would be misleading to any reader of the evaluation.

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Flight control mechanical characteristics Rotary wing

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

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SIMULATOR TEST AND EVALUATION

1. SCOPE.

This Test Operations Procedure (TOP) describes the methodology used for the evaluation of a flight simulator and can be used to support or implement verification and validation (V&V) activities in support of an accreditation. Verification is the process of determining that the simulator accurately represents the developer's conceptual description and specifications. Validation is the process of determining the extent to which the simulator is an accurate representation of the real-world from the perspective of its intended use. The TOP describes the initial fact-finding required, the requirements for aircraft test data, the set of subtests and the orderly progression through those subtests. This TOP assumes the tester is a graduate of a military test pilot school or equivalent.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Aircraft test data or an instrumented aircraft	Provide data to compare with simulator data as part of the assessment/validation process

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty
Force; Hand-held force gage (±20 kg)	±0.5% of reading
Flight Control Travel	±1 mm or ±1 degree
Field-Of-View Evaluation Apparatus (FOVEA)	±10 mil, ±1mm
Crewstation Dimensions	±0.5% of reading
Time	±0.1 second

3. REQUIRED TEST CONDITIONS.

3.1 Initial Research.

Research the simulator intended use, conceptual description and specifications, and technology. Identify the source and quality of the data used to build the simulator models and determine if the data quality supports the required fidelity.

3.1.1 Intended use.

Research the intended use of the simulator to determine what the simulator was designed to simulate. This will provide insight as to what degree of fidelity the simulator needs to demonstrate to be deemed suitable for the intended use. Ensure that the level of detail in the evaluation is appropriate for the simulator design/intended use and not excessively critical which would guarantee an adverse report.

3.1.2 Conceptual Description and Specifications.

Validate that the simulator's conceptual description and specifications are appropriate for the declared intended use. Obtain any existing V&V and/or Accreditation documentation for the simulator. Determine the level and quality of hardware and software documentation available for use during the test. Establish any limitations to use of the documentation from a proprietary or security standpoint.

a. Crewstation. Examine the simulator conceptual description/specifications to determine whether the crewstation will replicate the aircraft to an acceptable degree of accuracy with respect to the intended use.

(1) Flight Instruments. Determine how the crewstation flight instruments are driven and the source of the information displayed.

(2) Engine Instruments. Determine how the engine instruments are driven and the source of the information displayed.

(3) Ancillary Equipment. Determine which ancillary equipment is active in the simulator and the source of the appropriate signals.

b. Visual System. Assess whether the visual display requirements are appropriate for the intended use.

c. Crewstation Flight Controls. Assess whether the requirements for the crewstation flight controls replicate the aircraft to an acceptable degree of accuracy or whether actual aircraft hardware is installed.

d. Control Loader System. Assess whether the design characteristics of the control loader system are acceptable for the intended use.

(1) Technology. Identify the technology used to action the control loader system. Identify any limitations associated with the technology.

(2) Mechanical Characteristics. Identify the mechanical characteristics of the control loader system and flight controls.

(3) Control Feedback System. Identify the method used to provide control feedback forces to the flight controls.

(4) System Software/Hardware Control. Identify the system-controlling software and hardware. Determine the maximum frequency response and any and all time delays associated with the system control. Determine whether the simulator recording system is subject to any latency which might affect the validity of the data recorded. If the system can make flight control inputs independent of the aircrew, assess how that affects the simulator's validity

e. Flight Dynamics Model. Identify the flight dynamics model used to generate the simulator response to flight control inputs and external influences. Determine whether the model used is appropriate for the intended use of the simulator.

f. Motion System. Identify the motion system employed by the simulator and determine any limitations caused by the type of motion used.

g. Secondary Motion System. Identify any secondary motion used, its purpose and any inherent limitations.

h. Audio System. Identify any audio system used and the limitations of the system.

i. Instructor Station. Identify all functions of the instructor station.

j. Recording System. Determine the ability to record data via the embedded simulator recording system. Identify all the parameters that can be recorded, the source of the data and the data rate at which the parameter can be recorded. Identify any limitations inherent in the recording system. Identify the ability to record audio and video.

3.2 Engineering Support Requirements.

Establish the level of engineering support available from the simulator manufacturer. Ideally, on-site support from the flight dynamics engineer, the flight controls engineer, and the motion system engineer should be available for the duration of the simulator test.

3.3 Aircraft Data Source.

Determine the availability of aircraft data for quantitative comparison during the simulator test. The source of any data used must be fully documented, the accuracy must be known, and the data must come from the same aircraft configuration as the simulator. The data quality must be at least as high as the minimum standard to which the simulator is to be evaluated. Determine the availability of an instrumented aircraft to use for data gathering to support the simulator evaluation.

4. TEST PROCEDURES.

The tests described below should be performed in the order they are discussed. Ensure that the information gathered in paragraph 3 above is used to determine the level of fidelity required during testing. All results must be intended use relatable. All hazards, deficiencies, shortcomings, system specification non-compliance, and enhancing characteristics must be recorded.

4.1 Safety.

4.1.1 Crewstation.

Identify and document all safety related aspects of the crewstation. Emergency escape procedures should be tested and the results recorded. All emergency equipment must be tested to ensure that it is working correctly, that all emergency buttons, switches, or other devices can be reached easily from all positions in the crewstation, including the instructor station. Any automatic safety devices should be tested.

4.1.2 Motion System.

Identify and document all motion related safety features. This must include, but is not limited to motion limit features, motion rate limiters, safety interlocks for crewstation access, and all emergency stop methods.

4.1.3 Emergency Equipment.

Identify and document all emergency equipment associated with the simulator and any associated computer rooms. This will include all fire fighting equipment and systems, any emergency escape equipment, any emergency breathing equipment, and any first aid equipment. Escape procedures from the crewstation to the exterior of the building should be checked. Contingency equipment for power failures should be checked. All alarm systems should be checked.

4.2 Crewstation Evaluation.

4.2.1 Crewstation Fidelity.

Identify and document all aspects of crewstation fidelity which impact the intended use. Document whether aircraft hardware is used in the crewstation construction. Document seating positions and indicate where the positions differ from the aircraft. Relate the design-eye-position of the simulator and the aircraft.

4.2.2 Flight Control System Mechanical Characteristics.

The flight control mechanical characteristics (FCMC) of an aircraft or simulator have a significant impact on a pilot's perception of Handling Qualities (HQ). If the FCMC of the simulator do not match closely the FCMC of the aircraft, the difference may be perceived as a degradation in HQ, even if all other aspects match the aircraft. Consideration should be given to optimizing FCMC before proceeding beyond this test.

a. Calibrating the Simulator Data Recording System. Measure control force using a handheld calibrated force gage, and cockpit control positions using non-intrusive, linear and/or angular displacement indicators mounted to the controls and anchored to reference points on the instrument panel, center console, and cockpit doors. Record force and displacement on handheld data cards and compare the results to the simulator data using embedded simulator diagnostic tools. Static and dynamic forces should be checked. If the results indicate that the simulator correctly records actual force and displacement, then the simulator data can be used. If the results are not accurate, and the simulator cannot be recalibrated, hand-held measurements must be used.

b. Using the methodology described in U.S. Naval Test Pilot School Flight Test Manual No. 107 (FTM-107), Rotary Wing Stability And Control, Chapter 5, (Flight Control System Characteristics), determine the control envelopes, trim system freeplay, break-out forces, force gradients, and hysteresis of the simulator control system with the components of the automatic flight control system (AFCS) ON and OFF. Flight control axes which include a trim system will be tested with both TRIM ON and OFF and stability augmentation system (SAS) ON and OFF. The results will be compared to previously gathered aircraft data and any dissimilarities will be noted.

4.2.3 Visual Display.

Measure the extent of the visual display available to the crew from each pilot seat using the Field-Of-View Evaluation Apparatus (FOVEA). The FOVEA control head and camera should be placed on each pilot seat with the FOVEA camera at the design-eye-position for each seat. Map the boundaries of the external vision areas and compare the areas to the crewstation transparencies of the aircraft. Document the results.

4.2.4 Crewstation Lighting.

a. Ambient Lighting. Levels of ambient lighting should be assessed from bright sunlight through dark moonless night. Any areas of glare on crewstation transparencies should be noted and assessed for affect on the piloting task.

b. Pilot-Controlled Lighting. Assess the crewstation pilot-controlled lighting for accurate representation of the aircraft, for balance, and for any areas of glare on the crewstation transparencies.

4.3 Flying Qualities.

The extent of flying qualities data required will depend on the intended use for which the simulator was designed. Aircraft data must be available to compare to the simulator data or an instrumented aircraft must be available to collect data to compare to the simulator. The simulator must be configured in exactly the same way as the aircraft that was used to collect the truth data. Flying qualities tests may be undertaken with any primary motion system turned off initially to remove the effects of any inappropriate primary motion cues.

4.3.1 Stability and Control.

The simulator stability and control characteristics will be assessed using the methodology described in FTM-107. Open-loop and closed-loop test techniques should be used to define the simulator stability and control characteristics. Control inputs for engineering flight test maneuvers may be piloted or simulator-injected. The goal of stability and control testing is to determine the degree of similarity between the aircraft response to control inputs and the simulator response to the same control inputs under the same conditions. It is imperative that the control inputs used are derived from the flight test data being used to compare the simulator to the aircraft and that the similarity of the inputs and flight conditions are verifiable. If the scope of the test permits, the simulator flight dynamics engineer may make changes to the flight dynamics model to match the simulator characteristics to the aircraft data.

4.3.2 Performance.

The simulator performance characteristics will be assessed using the methodology described in U.S. Naval Test Pilot School Flight Test Manual No. 106 (FTM-106) Rotary Wing Performance. The degree to which the simulator should match the aircraft in performance terms is dependant on the intended use for which the simulator was designed – an instrument flying training device would require less fidelity than a device used for pilot qualification in all flight regimes. The simulator must be configured exactly as the aircraft that was used to generate the data for comparison.

4.4 Engine and System Indications.

Simulator engine and system indications should be checked for correct operation during simulator operation. Engine start sequences should match the aircraft, system pressures and temperatures should be checked. If the simulator is to be used for emergency situation diagnosis and subsequent action, the engine and system indications must match the aircraft or negative habit transfer may occur. The refresh rate for engine and system indications should be checked to determine if the rate is appropriate for the simulator intended use.

4.5 Flight Instrument Indications.

Simulator flight instrument indications should be checked for correlation between the flight control inputs, visual display reaction, and flight control indication. There should be no noticeable lag in the change of flight instrument indications following a control input.

4.6 Additional Crewstation Indications.

All additional crewstation indications necessary for the simulator intended use should be checked for correct indications.

4.7 Visual Display.

4.7.1 Display Lag.

The visual display system will be checked for any evidence of system lag. The simulator manufacturer/engineer should be able to provide the known system lag based on analysis of the software and hardware links from the flight control input through the flight dynamics model response to the visual display system response. An average aircraft displays a lag of approximately 100 m/s between control input and aircraft response; display lags of up to approximately 250 m/s have been shown to be acceptable, albeit with some increase in workload and decrease in performance (USAARL Report No. 96-38). Higher gain tasks require less display lag for optimum performance so the effect of display lag is simulator intended use dependant.

4.7.2 Display Content.

The level of detail and texture used in display systems has an impact on the suitability of a display for a given task. Tasks involving landing and take-off, hovering, or high-gain tasks require a greater level of display content and texture than low gain, higher altitude tasks. For precision tasks, display elements that provide cues to relative movement, height above the ground, and relative object size are required. Identifiable buildings, vehicles, aircraft, people, and animals are all useful items for inclusion in a visual scene. Items such as trees and runways do not provide the relative information that pilots require for perspective.

4.7.3 Display Consistency.

The display should be assessed for consistency across the entire field-of-view. Boundaries between display video should not be noticeable to the pilot. Straight lines should be consistently straight in the image, edges of buildings, runways etc, should be sharply defined. Different weather conditions should be assessed as should any night scenes.

4.8 Audio Cues.

Audio cues that relate directly to the piloting task should be assessed. These could include rotor noise, engine noise, weather related noise, and any on-board audio annunciations associated with aircraft systems. Any audio cues provided should enhance, not detract from, the pilot's situational awareness.

4.9 Motion Cues.

Simulator motion systems typically comprise primary and secondary motion systems. Primary motion systems provide movement of the simulator itself to provide the pilot with proprioceptive cues to accelerations, rates, and attitudes. Secondary motion systems provide additional cues including rotor vibrations, translational lift vibrations, and aircraft harmonics. Additional motion cues may be provided for landing gear dynamic feedback, atmospheric turbulence, weapons firing, and other effects.

4.9.1 Primary Motion.

There is little quantitative guidance for primary motion systems in the industry. Whilst it is generally true that motion is a preferred option for a simulator, an untuned motion system can have a significant detrimental effect on the piloting task. One approach can be found in the Federal Aviation Administration Advisory Circular 120-63 (Helicopter Simulator Qualification). Alternatively, select some relevant mission maneuvers, fly the maneuvers with and without motion, and determine whether the pilot's performance is enhanced or degraded by the motion system. Motion cuing consists of accelerations in the appropriate axes, washouts of those accelerations, and resultant attitudes. Inconsistencies in motion cuing may be isolated by flying single axis maneuvers such as accelerations and decelerations, or lateral sidestep maneuvers, and determining if the motion cuing is correct in each axis (ADS-33E-PRF, Chapter 4). Some tuning of the system may be possible if on-site engineering support is available.

4.9.2 Secondary Motion.

Evaluate the secondary motion system throughout the flight envelope to determine if it is appropriate for the various phases of flight or if it is intrusive and detrimental to the piloting task. Some tuning may be possible if on-site engineering support is available.

4.10 Mission Equipment.

Any mission equipment included in the simulation should be checked for accurate representation of the aircraft mission equipment. Weapons systems, aircraft survivability equipment, radars, forward-looking infrared sensors, and other relevant equipment should be checked for realistic operation and for accurate crew interfaces.

5. DATA REQUIRED. Table 1 contains a typical list of parameters required:

Table 1. Sample Parameter List[1].

Airspeed	Angle of sideslip
Control positions (longitudinal cyclic, lateral cyclic, directional control, collective)	Stability and control augmentation system (SCAS) actuator positions (left, right, directional)
Control forces	
Linear accelerations (cg normal, cg lateral, cg longitudinal)	Aircraft angular rates (pitch, roll, yaw)
Angle of attack	Aircraft attitudes (pitch, roll, yaw)
Trim System State	Weight-on-Wheels Switch State
Pressure altitude	Radar altitude
Rate of climb	Total air temperature
Time code display (hr, min, sec, msec)	Run number
Main rotor speed	Main rotor mast torque
Fuel totalizer	Aircraft weight and cg
Engine gas generator speed	Engine power turbine speed
Engine turbine gas temperature	Engine torque
Engine fuel flow	Engine compressor discharge pressure

NOTE:
[1]Determine the recording capability of the system. A trade-off may be required between the number of parameters to be recorded vice the record length.

6. PRESENTATION OF DATA.

6.1 Simulator Evaluation Data.

In addition to written paragraphs for each aspect of the simulator evaluated, comparison data may be presented to demonstrate the similarity or otherwise between the simulator and the aircraft.

6.1.1 Flight Control Mechanical Characteristics.

a. Flight Control Envelope Plots.

b. Flight Control Force versus Displacement Plots.

c. Beeper Trim Rate versus Displacement Plots.

6.1.2 Field-of-View Evaluation Apparatus Plots.

6.1.3 Stability Plots.

a. Static Stability Plots.

b. Dynamic Stability Plots.

c. Maneuvering Stability Plots.

6.1.4 Time Histories of Control Response Tests.

6.1.5 Frequency Domain Plots.

6.1.6 Aircraft Performance Plots.

a. Hover Performance.

b. Forward Flight Climb and Descent Performance.

c. Level Flight Performance.

d. Autorotational Performance.

6.2 Presentation of V&V Results.

The results from this TOP should be used to support or supplement required V&V and Accreditation activities for the simulator. The format for this data is dependent upon the application sponsor. Appendix B contains references to DoD, Army, Navy, ITOP, and ATEC M&S VV&A policies that could be applicable depending upon the application sponsor.

APPENDIX A. GLOSSARY

Term	Definition
AFCS	Automatic Flight Control System
FCMC	Flight Control Mechanical Characteristics
FOVEA	Field-of-View Evaluation Apparatus
FTM	Flight Test Manual
HQ	Handling Qualities
M&S	Modeling and Simulation
SAS	Stability Augmentation System
SCAS	Stability and Control Augmentation System
TOP	Test Operations Procedure
USAARL	US Army Aeromedical Research Laboratory
V&V	Verification and Validation
VV&A	Verification, Validation, and Accreditation

APPENDIX B. REFERENCES.

1. U.S. Naval Test Pilot School Flight Test Manual No. 107, Rotary Wing Stability and Control, 31 December 1995.

2. U.S. Naval Test Pilot School Flight Test Manual No. 106, Rotary Wing Performance, 31 December 1996.

3. Federal Aviation Administration Advisory Circular 120-63, Helicopter Simulator Qualification, 11 October 1994.

4. ADS-33E-PRF, Aeronautical Design Standard Performance Specification, Handling Qualities Requirements for Military Rotorcraft, U.S. Army Aviation and Missile Command, Aviation Engineering Directorate, Redstone Arsenal, Alabama, 21 March 2000.

For information only (related publications).

a. Aviation Engineering Flight Activity Project No. 86-23, UH-60 Flight Simulator Evaluation, August 1989.

b. NASA Technical Memorandum 86818, Visual and Motion Cuing in Helicopter Simulation, September 1985.

c. U.S. Army Aeromedical Research Laboratory Report No. 96-38, Visual Display Delay Effects on Pilot Performance, September 1996.

d. American Institute of Aeronautics and Astronautics-91-2892, Simulation Evaluation of the Effects of Time Delay and Motion on Rotorcraft Handling Qualities, 12 August 1991.

e. NASA Technical Memorandum 110385/U.S. Army Aviation and Troop Command Technical Report 96-A-006, A Simulation Investigation of Motion Cuing and Visual Time Delay Effects on Two Helicopter Tasks, April 1996.

f. Department of Defense Instruction 5000.61, DoD M&S Verification, Validation, and Accreditation, 13 May 2003.

g. Army Regulation 5-11, Management of Army Models and Simulations, 1 February 2005.

h. ATEC Regulation 73-21 Accreditation of M&S for Test and Evaluation, 23 August 2004.

i. ITOP 1-1-002 General Guidance for M&S V&V Information Exchange, May 2004.

j. Department of Defense VV&A Recommended Practices Guide, September 2006.

k. Department of the Army Pamphlet 5-11 VV&A of Army M&S.

l. ATEC Pamphlet 73-21 M&S VV&A Methodology, 13 April 2007.

m. SECNAVINST 5200.40 Department of the Navy VV&A of M&S, 19 April 1999.

n. SECNAVINST 5200.38A Department of the Navy M&S Management, 28 February 2002.

o. OPNAVINST 5200.34 Navy M&S Management, 28 May 2002.

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